CHAPTER 11

ACTIVATED SLUDGE PLANTS

11-1. General considerations. The activated sludge process is a biological treatment process in which a mixture of wastewater and microorganisms is agitated and aerated. The activated sludge mixed liquor is subsequently separated by sedimentation, and the sludge is returned to the process, with some withdrawn as waste sludge. This chapter presents the different modifications of the conventional activated sludge process, including general bases for design, methods of aeration, and design factors for aeration tanks, final sedimentation units, and sludge handling systems. All designed processes will include preliminary treatment consisting of screening as a minimum.

a. Basic process. Basically the activated sludge process uses microorganisms in suspension to oxidize soluble and colloidal organics to carbon dioxide and water in the presence of molecular oxygen. During oxidation, portions of the organic material are synthesized into new cells. Oxygen is required to support the oxidation and synthesis reactions. The solids generated must be separated in a clarifier for recycle to the aeration tank; the excess sludge is withdrawn for treatment and disposal.

b. Modifications of the process. Modifications to the conventional activated sludge process include step aeration, contact stabilization, plug flow, completely mixed, and extended aeration systems.

11-2. Activated sludge processes. The two basic reactor types are plug-flow and complete-mix models. In plug flow, fluid particles pass through the tank and are discharged in the same sequence in which they enter. Complete mixing occurs when the particles entering the tank are immediately dispersed throughout the tank. Because of the continuous mixing, completely mixed units are less susceptible to upsets caused by toxic chemicals or shock loadings than are plug-flow units.

a. Conventional activated sludge. In a conventional (plug-flow) activated sludge plant, the primary-treated wastewater and acclimated microorganisms (i.e., activated sludge or biomass) are aerated in a basin or tank. After a sufficient aeration period the flocculent activated sludge solids are separated from the wastewater in a secondary clarifier. The clarified wastewater flows forward for further treatment or discharge. A portion of the clarifier underflow sludge is returned to the aeration basin for mixing with the primary-treated influent to the basin, and the remaining sludge is returned to head of plant. The portion recirculated is determined on the basis of the ratio of MLVSS to influent wastewater BOD which will produce the maximum removal of organic material from the wastewater. Recirculation varies from 25 to 50 percent of the raw wastewater flow, depending on treatment conditions and wastewater characteristics. A flow schematic for a conventional activated sludge plant is shown in figure 11-1a.

b. Step aeration. In this process, the influent wastewater is introduced at various points along the length of the aeration tank. Sludge return varies between 25 and 50 percent. Aeration or the oxygen requirement during step aeration (3 to 7 hours) is about half that required for the conventional process. This results from a more efficient biomass utilization in the aeration basin, allowing organic loadings of 30 to 50 pounds BOD per 1,000 cubic feet per day, as compared to loadings of 30 to 40 pounds BOD per 1,000 cubic feet per day permitted for conventional systems. A flow schematic for a step aeration activated sludge plant is shown in figure 11-1b.

c. Contact stabilization. The contact stabilization activated sludge process is characterized by a two-step aeration system. Aeration of short duration (1/2 to 2 hours) is provided in the contact tank, where raw or primary settled wastewater is mixed with the activated sludge in the contact tank. The effluent from the contact tank is then settled in a final settling tank. The settled activated sludge to be recycled from the final clarifier is drawn to a separate reaeration or stabilization basin for 3 to 6 hours of aeration time. It is then returned to the contact aeration basin for mixing with the incoming raw wastewater or primary settled effluent. In addition to a shorter wastewater aeration time, the contact stabilization process has the advantage of being able to handle greater shock and toxic loadings than conventional systems because of the buffering capacity of the biomass in the stabilization tank. During these times of abnormal loadings, most of the activated sludge is isolated from the main stream of the plant flow. Contact stabilization plants will not be used unless daily variations of hydraulic or organic loadings routinely exceed a ratio of 3:1 on consecutive days. A flow schematic for a contact stabilization activated sludge plant is shown in figure 11-1c.

d. Completely mixed activated sludge. In the completely mixed process, influent wastewater and the recycled sludge are introduced uniformly through the aeration tank. This allows for uniform oxygen demand throughout the aeration tank, and adds operational stability when treating shock loads. Aeration time ranges between 3 and 6 hours. Recirculation ratios in a completely mixed system will range from 50 to 150 percent. A flow schematic for a completely mixed activated sludge plant is shown in figure 11-1d.

e. Extended aeration. Extended aeration activated sludge plants are designed to provide an aeration period of from 18 to 36 hours for low organic loadings of less than 20 pounds BOD per 1,000 cubic feet of aeration tank volume. This approach, which is to be used for treatment plants of less than 0.1 mgd capacity, reduces the amount of sludge

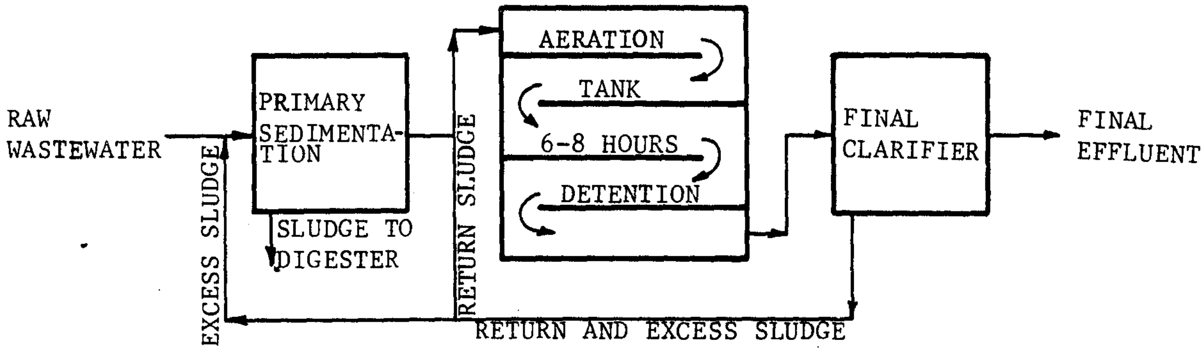

FIGURE 11-1a CONVENTIONAL ACTIVATED SLUDGE FLOW DIAGRAM

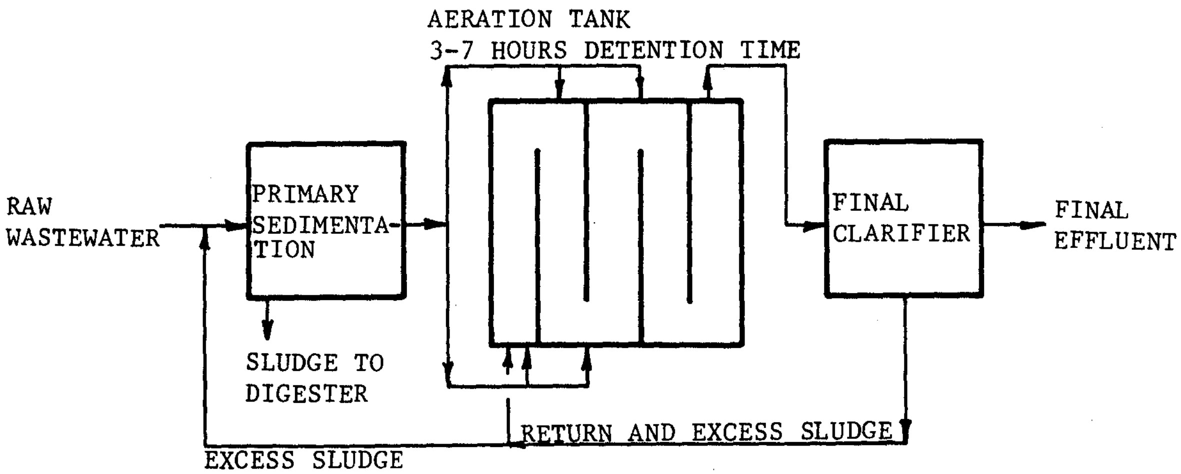

FIGURE 11-1b STEP AERATION FLOW DIAGRAM

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FIGURE 11-1. ACTIVATED SLUDGE FLOW DIAGRAMS

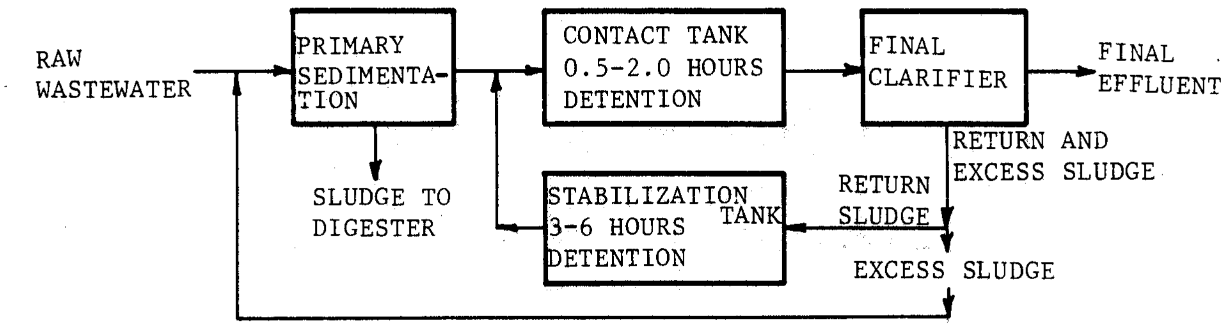

FIGURE 11-1c CONTACT STABILIZATION FLOW DIAGRAM

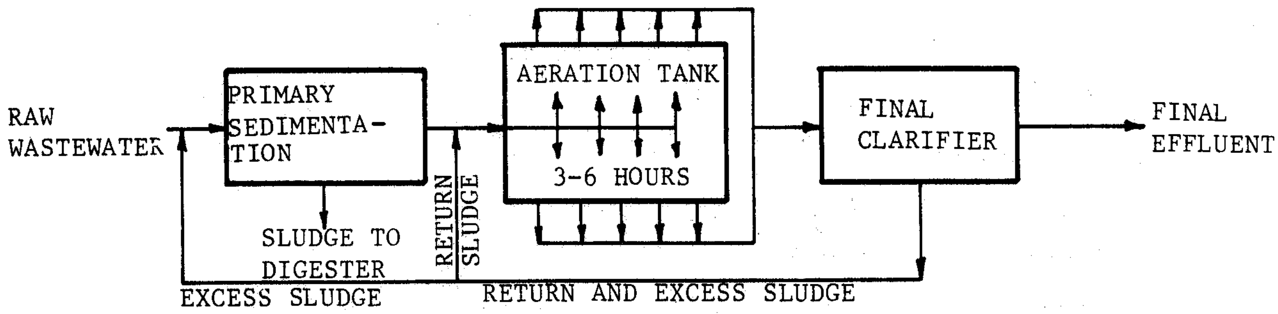

FIGURE 11-1d COMPLETELY-MIXED FLOW DIAGRAM

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FIGURE 11-1. ACTIVATED SLUDGE FLOW DIAGRAMS (CONTINUED) being wasted for disposal. It will be considered as an option in larger plants.

f. Oxidation ditch process. The oxidation ditch process is an attractive alternative for Army application. The process is simple to operate and maintain and performs reliably without highly skilled operators. There are few moving parts which can wear out or fail. By their very nature, oxidation ditches provide flow equalization -- an important requirement for Army plants. They need no primary clarifier and produce a stabilized sludge which requires no further treatment (i.e., no anaerobic digester). Despite their simplicity, oxidation ditches are a flexible technology and can be configured not only for BOD oxidation, but also for nitrification and denitrification. Oxidation ditches have lower capital and operation and maintenance costs than any other biological process for the capacity range within which 75 percent of all Army plants fall.

(1) An oxidation ditch is a modification of the activated-sludge treatment process. It is commonly operated in an extended aeration mode, although conventional activated-sludge treatment is also possible. Typical oxidation ditch treatment systems consist of a single, closed-loop channel 4 to 8 feet deep, with 45 degree sloping side walls.

(2) Some form of preliminary treatment, such as screening, normally precedes the oxidation ditch process. Primary clarification is usually not done. Single or multiple mechanical aerators are mounted across the channel, in a fixed or semi-fixed floating position. Horizontal-brush, cage, or disc-type aerators or vertical-shaft aerators designed for oxidation ditch applications are normally used. The aerators provide mixing and circulation in the ditch, as well as sufficient oxygen transfer. Besides BOD removal, a high degree of nitrification may occur without special modifications because of the ditch's long detention time (normally 16 to 24 hours) and the long solid retention time (10 to 50 days). Secondary clarification is provided in a separate clarifier, although an intrachannel clarification modification may be used, if feasible.

(3) Ditches may be built of various materials, including concrete, shotcrete, asphalt, or impervious membranes. Concrete is the most common. Ditch loops may be oval or circular, although "ell" and "horseshoe" configurations have been used to maximize land usage.

11-3. Design basis and criteria.

a. Design formulation. Table 11-1 provides design criteria. Standard design values provided hereinafter will be used.

Table 11-1. Design Criteria for Activated Sludge Modifications

Process Type	Design Flow mgd	Aeration Period hours	BOD Loading pounds/1,000 cubic feet
Conventional	below 0.5	7.5	30
	0.5 to 1.5	7.0	35
	above 1.5	6.0	40
Step Aeration	below 1.5	6.0	30
	above 1.5	5.0	50
Complete Mix	All	6.0	50
Extended Aeration	below 0.1	18 to 36	<20
Contact Stabilization	below 0.5	2.0 contact 5.0 reaeration	30
	0.5 to 1.5	1.5 contact 5.0 reaeration	40
	above 1.5	1.0 contact 4.0 reaeration	50

b. Aeration period. The required aeration period is a function of influent characteristics, mixed liquor volatile suspended solids concentration, and BOD removal rate. The design aeration period is the hydraulic detention time and is equal to the volume of the reactor divided by the design influent wastewater flow rate.

c. Organic loadings. The organic loadings are tabulated in table 11-1 for the design of specific activated sludge processes and plant sizes.

d. Sludge production. Excess sludge production in an activated sludge plant will be estimated to be between 0.4 and 0.7 pound VSS/pounds BOD removed, for normal organic loadings of 0.3 to 0.6 pound BOD/pounds MLVSS/day. Waste sludge will be returned to the head of the primary clarifier for thickening with the primary sludge.

11-4. Methods of aeration. Aeration in the activated sludge process may be achieved through diffused aeration, mechanical aeration, or a combination of both.

a. Air requirements. Table 11-2 contains ranges for oxygen and air required per pound of BOD removed for the activated sludge modifications previously discussed. These values represent overall process requirements. The total amount of oxygen required will vary within the ranges shown depending upon the food to microorganism ratio (F/M) or pounds BOD/pound MLVSS, increasing as F/M decreases. In diffused air systems, the air requirements will vary depending on the oxygen transfer efficiency of the diffusers employed. The designer must recognize that the various process modifications will require different air and oxygen distribution patterns. Also the values shown in the table do not include allowances for nitrification or for other plant air requirements.

Table 11-2. Oxygen and Air Requirements for Activated Sludge Modifications

Process	lb O_2/lb BOD Removed[1]	scf Air/lb BOD Removed[1,2]
Conventional	0.8 - 1.1	800 - 1,500
Step Aeration	0.7 - 1.0	800 - 1,200
Contact Stabilization	0.7 - 1.0	800 - 1,200
Complete Mix	0.7 - 1.0	800 - 1,200
Extended Aeration	1.2 - 1.5	1,700 - 2,000

[1]Use mid-point value for design purposes.

[2]Assuming air equipment is capable of transferring 1.0 pound of oxygen to the mixed liquor per pound of BOD aeration tank loading. To these air volume requirements will be added air required for channels, pumps, or other air-use demand.

b. Oxygen transfer rates. The oxygen transfer rates in wastewater are affected by various physical and chemical variables, such as temperature, degree of turbulent mixing, pressure, liquid depth, type of aeration device, and chemical characteristics of the wastewater. Aeration equipment will be required to maintain a minimum of 2.0 mg/l of dissolved oxygen in the mixed liquor at all times and provide thorough mixing of the aeration tank or basin contents.

(1) Diffused air systems. Porous, plate, and tube diffusers are the most common types used for diffused-air aeration systems. These devices have demonstrated approximately the same oxygen transfer efficiency. Specific selection will be based on cost of installation and anticipated cost of maintenance. Individual assembly units of diffusers will be equipped with control valves. Diffusers in any single assembly will have substantially uniform pressure loss.

Nonporous diffusers such as ejectors, impingement plates, jet-air diffusers, helix-type diffusers, and nozzles are used for aerating mixed liquor in activated sludge processes. Many of these diffusers require as much as 50 percent more air than porous diffusers.

(2) Provisions for cleaning. Selection and design of diffuser systems must include provisions for cleaning the diffusers and for cleaning the air supply to minimize clogging disruptions of the activated sludge processes.

c. Blowers and piping.

(1) Blowers. The supplying of air by blowers for the activated sludge process constitutes a major power requirement. Blowers will be provided in multiple units, with arrangement and capacities to meet the maximum oxygen demand with the largest unit out of service. Positive-displacement rotary and centrifugal blowers are acceptable. Centrifugal blowers will be permitted only when unit capacity requirements call for free air flows equal to or greater than 15,000 cfm. As a conservation measure, sludge-digestion gas can be more efficiently used as fuel for driving positive-displacement blowers than for driving electric generators. The type, size, and number of blowers required will be determined by the anticipated maximum, peak, average, low, and minimum oxygen demands.

(2) Piping. Air mains will be designed so that pressure loss will be negligible and so that uniform air flow through each square foot of distributed surface is attained. The air diffusion piping and diffuser system will be capable of delivering 200 percent of the normal air requirements. It is essential that the interior of the air pipes remain free from corrosion and scaling that might cause clogging of the diffusers. Expansion and contraction joints should be part of the piping design. Blower discharges and air delivery to aeration tanks should be metered by orifice or Venturi-type flow meters.

d. Mechanical aerators.

(1) Surface and turbine. Surface aerators may be fixed or floating devices with high-speed, low-speed, two-speed, or variable-speed motors. Floating aerators are applicable for use where the water elevation fluctuates, or where rigid support would be impractical. Slow-speed surface aerators are considerably more expensive than high-speed units despite the fact both units have essentially the same oxygen transfer efficiencies; however, low-speed mechanical surface aerators are more reliable and provide better mixing. Turbine aerators are not as efficient as surface aerators but are useful where basin area limitations will not permit the use of mechanical aerators. An advantage of mechanical aeration over diffused-air aeration lies in the relative simplicity of mechanical equipment. Mechanical aerators in common use are proprietary devices

with unique, usually patented characteristics. Aerator design will be based on the most adverse climatic conditions anticipated, when oxygen transfer efficiencies are lowest, to assure adequate capacity.

(2) Oxygen transfer capability. The oxygen transfer capability of aeration equipment will be determined by the following formula:

$$N = N_o \frac{(C_{sw} - C_L)}{C_s} \times 1.024^{T-20} \times \alpha$$

where:

$C_{sw} = \beta \times C_s$

$$\text{Alpha } (\alpha) = \frac{\text{oxygen transfer coefficient in wastewater}}{\text{oxygen transfer coefficient in tapwater}}$$

$$\text{Beta } (\beta) = \frac{\text{oxygen saturation value in wastewater}}{\text{oxygen saturation value in tapwater}}$$

Use $\alpha = 0.8$ and $\beta = 0.9$ unless laboratory data are available to demonstrate other values.

N = pounds O_2/hp-hour transferred at design conditions
N_o = pounds O_2/hp-hour transferred at standard conditions as rated by the manufacturer.
C_{sw} = saturation value of dissolved oxygen at design temperature and specific elevation (appendix B).
C_s = saturation value of dissolved oxygen of tapwater at 20 degrees C. and sea level; use 9.2 mg/l.
C_L = DO level (mg/l) desired at design conditions; use 2 mg/l.
T = Design operation temperature (degrees C.).

The designer will compute the value of N for summer and winter temperatures. The aeration equipment will be selected on the basis of the lower value of N, i.e., the lower rate of transfer.

(3) Mixing requirement. For diffused-air systems, a minimum of an additional 20 scfm/1,000 cubic feet of aeration tank volume will be provided to insure good mixing. To maintain a completely mixed flow regime with mechanical aerators, allow 1.9 hp/1,000 cubic feet of aerated volume. Mixing horsepower requirements usually control aerated lagoon designs; that is, the total horsepower required for mixing is larger than the total horsepower required to meet the design oxygen demand.

e. Combination of diffused and mechanical aerators. In the last 20 years, many manufacturers have introduced equipment that mechanically disperses the air after being diffused in the aeration tank. In some of these devices, air is introduced through spargers and then dispersed by means of a turbine mixer. Table 11-3 lists power requirements associated with various types of aerators.

Table 11-3. Power Requirements for Different Types of Aerators

Type of Aeration System	Oxygen Delivered pounds O_2/hp/hour	Power Required kW-hour/pounds O_2
Diffused Air, Fine-Bubble	2.1	0.35
Diffused Air, Coarse-Bubble	1.4	0.55
Mechanical Aerator, Vertical Shaft (Surface Aerator)	3.7	0.20
Agitator Sparger System	2.1	0.35

11-5. Aeration tank design.

a. Number and arrangement of aeration tanks. If the total aeration tank volume exceeds 5,000 cubic feet, except for the extended aeration process, the total capacity will be divided into two or more units capable of independent operation. Diffused-air aeration tanks, rectangular in shape, will be divided into one or more channels in such a manner that the length of travel exceeds four times the width of the channels. Inlets and outlets for each aeration tank will be suitably equipped with valves, gates, stop plates, weirs, or other devices to facilitate control of the flow and liquid levels in the tank. Channels and pipes carrying liquids with solids in suspension will be designed to maintain self-cleaning velocities (i.e., not less than 2 fps). Devices for indicating flow rates of raw sewage or primary effluent, return sludge, and air to each aeration tank will be provided.

b. Aeration tank volume. Aeration tank volume must satisfy the following criteria (if more than one of these is applicable in a given situation, the most stringent must be satisfied):

(1) A minimum detention time (aeration time), as stated in paragraph 11-3.

(2) The limitation of volumetric loading (pounds BOD/1,000 cubic feet/day).

(3) The limitation of organic loading expressed in pounds BOD/day/pound MLVSS.

(4) A desirable ratio of pound BOD/pound MLVSS is to be maintained in the aeration tank. This ratio will range from 0.25 to 0.5 in conventional plants and from 0.2 to 0.5 in Step Aeration and

Contact Stabilization. For extended aeration, this ratio varies between 0.03 and 0.2.

(5) An optimum BOD-to-nutrient ratio of 100:5:1 of BOD : Nitrogen : Phosphorus is to be maintained for proper microbiological growth. Domestic wastewater does not need any supplemental nutrients, but if some industrial wastes encumber the system, some nutrient addition may be required.

c. Aeration tank dimensions.

(1) Conventional activated sludge. Minimum tank depth, side-water depth, (SWD), will be 7 to 10 feet for small plants (0.1 mgd) and from 10 to 14 feet for larger plants; minimum free board will be 2 feet. The tank bottom will slope along the longitudinal axis to a sump. Aeration tank width will be 1.65 to 2.0 times the SWD; the larger ratio is the width used for deeper tanks. For example, a tank with a SWD of 10 feet will be 16.5 feet wide, while a tank with a SWD of 15 feet will be 30 feet wide. However, these limitations do not apply to a completely mixed system.

(2) Completely mixed activated sludge. Aeration tanks will be designed in a manner to insure proper turbulent flow of wastewater. For diffused-air systems, the air diffusers will be installed along one side of the channel and near its bottom. The opposite bottom corner will have a fillet of concrete, and deflector baffles (at an angle of approximately 45 degrees) placed at the water surface so as to assist in maintaining the desired circulation of liquid in the tank. The traverse velocity across the bottom of these tanks should be at least 1 fps and preferably 1.5 fps in order to prevent deposition of solids in the tank bottom. For mechanical aerator systems, the installed horsepower should not exceed 2.5 hp/1,000 cubic feet of the tank's liquid volume. The minimum liquid depth will be 10 feet and the maximum depth 12 feet. Draft-tube aerators must be used for depths greater than 12 feet, and the largest horizontal distance of the unit from wall to wall will be 24 feet. If circular tanks are used for mechanical aeration systems, internal wall baffles will be provided in order to prevent potential vortexing problems. If more than one aerator is required for an aeration basin, the minimum center-to-center spacing of the units, in feet, will be 0.8 times the unit aerator horsepower.

11-6. Final settling tank. It will be the function of the final sedimentation tank to remove solids from the aeration tank effluent. The final sedimentation tank will be designed to handle a flow equal to the projected design raw wastewater flow. The design will provide for the sludge return to the aeration tank. The design parameters indicated in paragraphs 8-3.b. and 8-4. should be observed.

11-7. Sludge handling.

a. Sludge return. Provisions will be made for returning sludge from the secondary settling tank to the aeration tank by centrifugal pumps or air lifts; return sludge piping will be at least 4 inches in diameter and will be designed to avoid sludge velocities of less than 2 fps. A continuous purge system will be provided which means that a water supply of suitable quality, volume, and pressure must be provided at the metering site. The sludge return rates, expressed as a percentage of the average forward flow of wastewater, that will be obtainable for specific activated sludge processes are as follows:

	Minimum*	Normal	Maximum*
Conventional Activated Sludge	25	30	50
Completely Mixed	50	100	150
Step Aeration	25	35	50
Contact Stabilization	50	100	150
Extended Aeration	50	100	200

*Sludge pump and piping design will permit these sludge recycle rates to be obtainable.

b. Sludge wasting. Sludge in excess of the quantity returned to the aeration tank will be returned to the inlet end of the primary settling tank for settling and concentration. Waste sludge control facilities will have a maximum capacity of at least 25 percent of the average rate of wastewater flow and must function satisfactorily at rates of 0.5 percent of the average flow or 10 gpm, whichever is larger.